# Summary of OTD Research Efforts and Opportunities Related to Assessment of Dents and Cracks

**September 11, 2018**
**Government & Industry Pipeline R&D Forum, Baltimore, MD**
**Working Group #1 – Improving Assessment Methods for Dents and Cracks**

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# Topics to Cover

- Alternative to Hydro-Testing Program – Critical Crack **Sizes**
- Advanced Crack **Development** and **Growth** Model
- Leak Rupture Boundary Determination – Crack **Failure Mode**
- Current Challenges Related Threat **Interactions**
- Summary of Previous Work and **Future** Research Needs

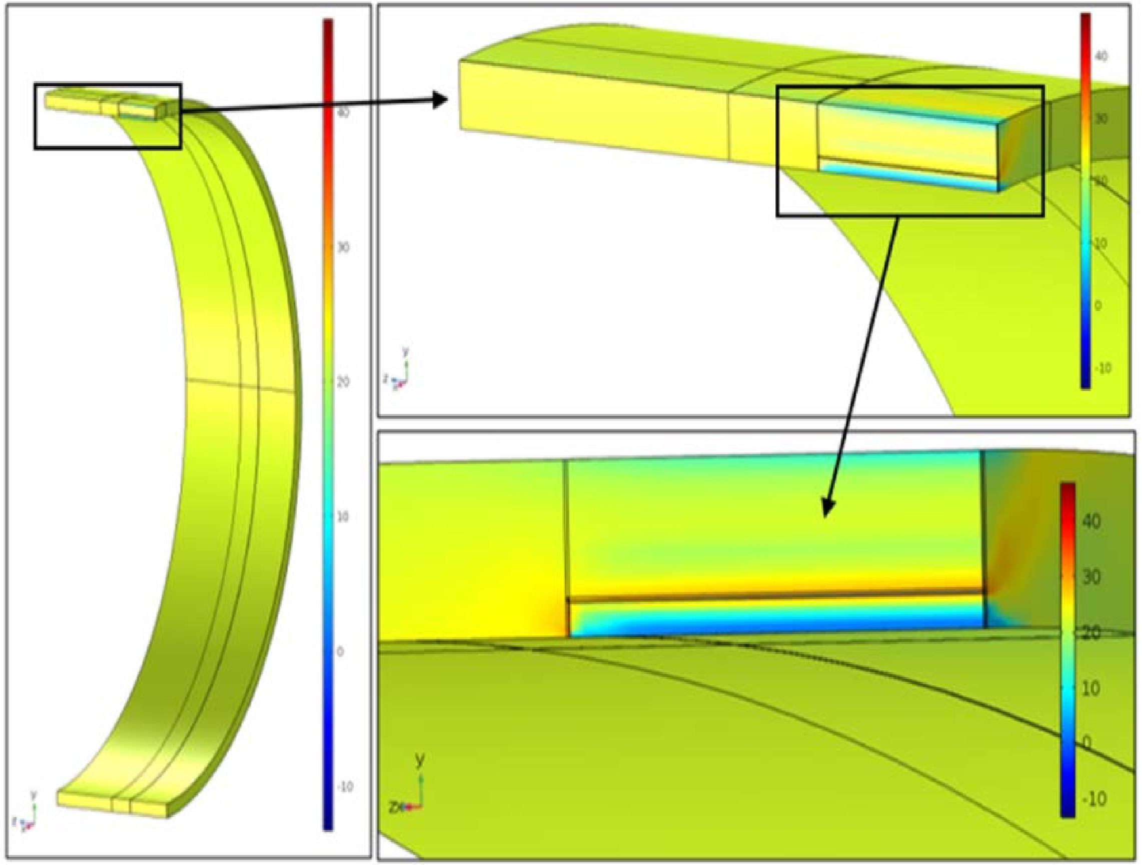
# Hydro-testing Alternative Program

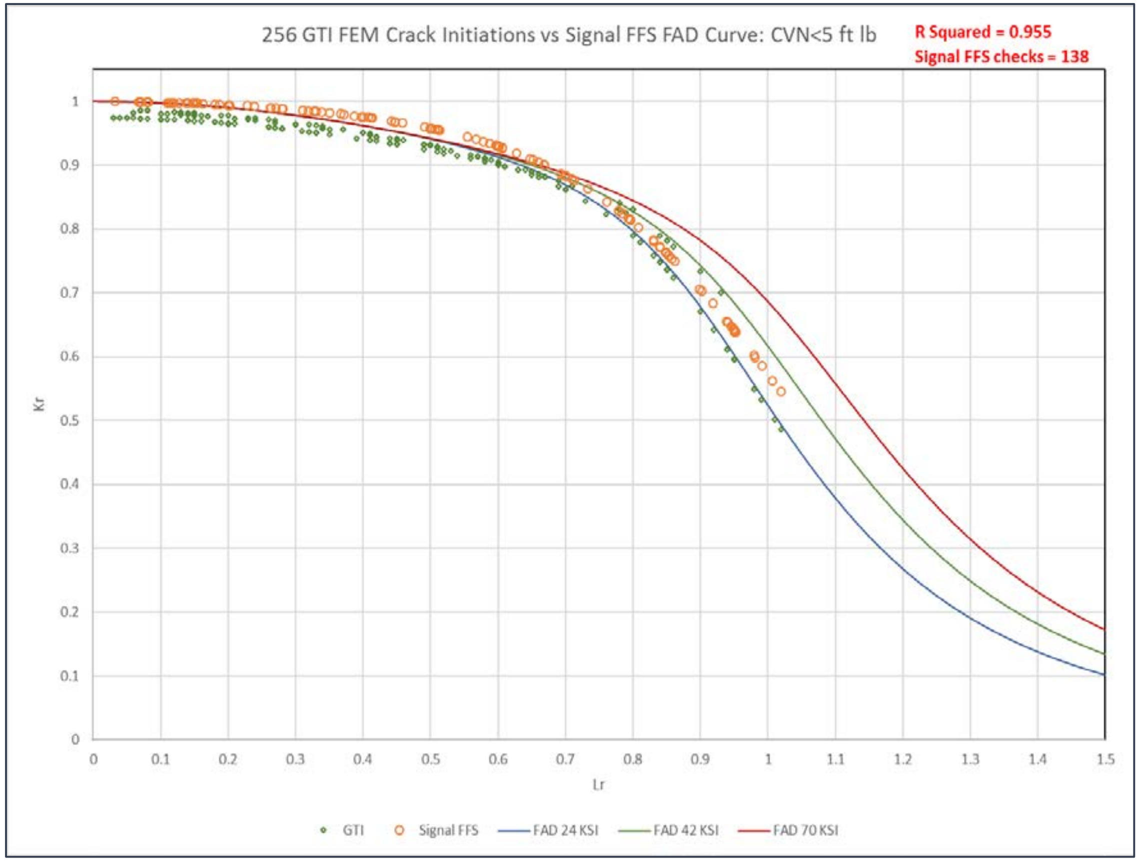
## A Critical Flaw and Wall Loss Model

- Developed a Critical Flaw and Wall Loss Model and Calculator to confirm if an inspection technology would detect a crack-like flaw and/or wall loss that would fail a pressure/hydro test.
- Provided an integrity assessment solution for pipelines that cannot be taken out of service to perform a hydro test.
- Currently helping ensure the safety of the pipeline while providing cost savings to complying with new/pending regulations.
- Avoid problems with hydro-testing, such as risk of introducing water that cannot be removed or accelerating crack growth for susceptible materials.

# 3D Model with Crack Propagation and Validation

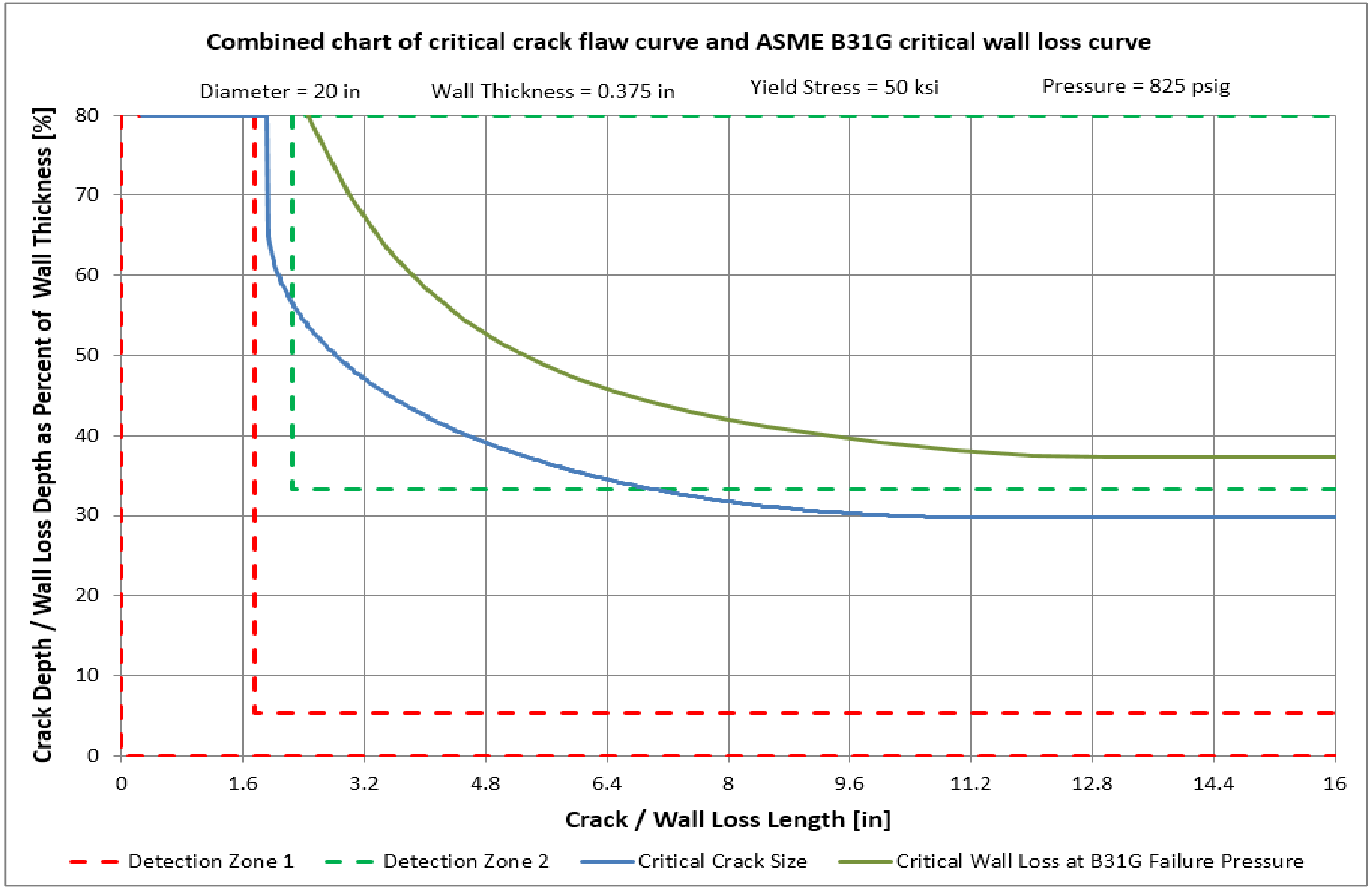
## Hydro-testing Alternative Program





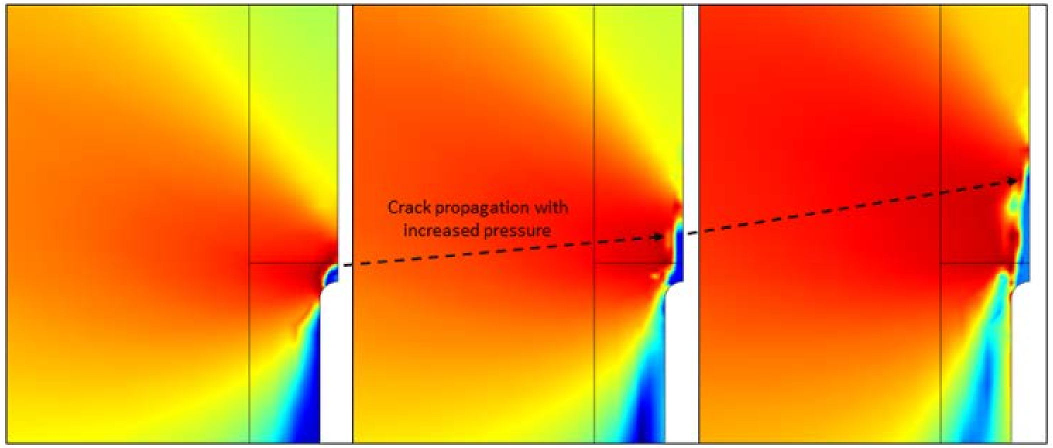
# Results – Calculator and Critical Curves

## Hydro-testing Alternative Program



# Advanced Crack Growth Modeling Project

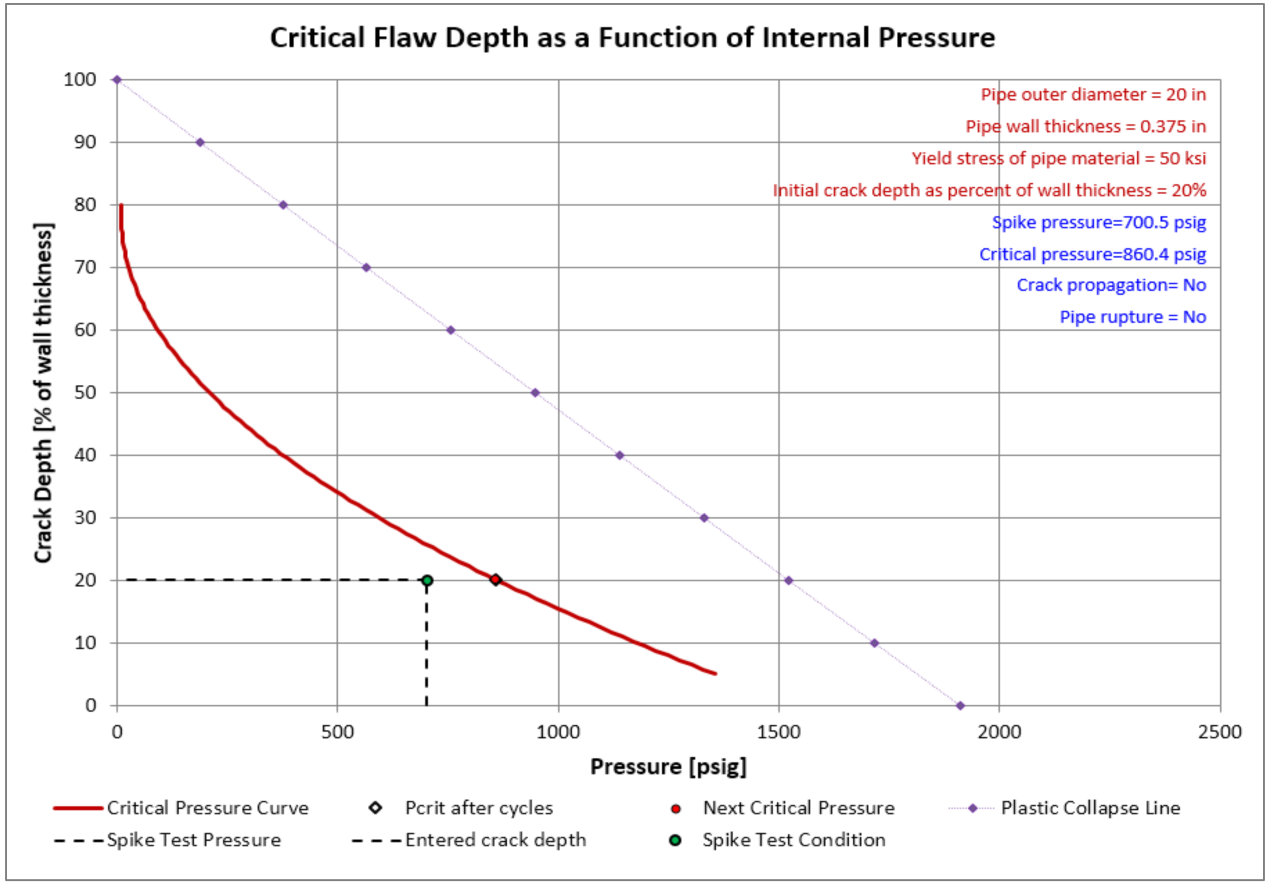
- The Advanced Crack *Propagation* project successfully developed the material models necessary to properly model crack *initiation* in pipeline steels using finite element methods (FEM).
- A closed form solution fit the results of the FEM model for critical pressure and length of crack *propagation* with a predicted $R^2$ greater than 0.98.
- A detailed calculator using the response surfaces was developed.



# Operator Calculator

## Advanced Crack Growth Modeling Project

- A model calculator takes user **inputs**
  - pipe diameter
  - pipe wall thickness
  - grade (yield strength)
  - initial crack depth
  - MAOP
  - spike over-pressure as %MAOP
  - number of pressure test cycles
- The calculator provides the following **outputs**
  - critical flaw depth as a function of internal pressure plot
  - critical pressure and arrested crack depth at the critical pressure

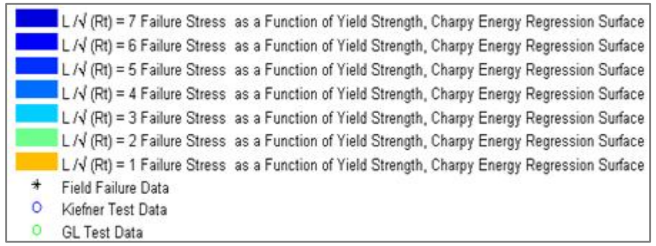


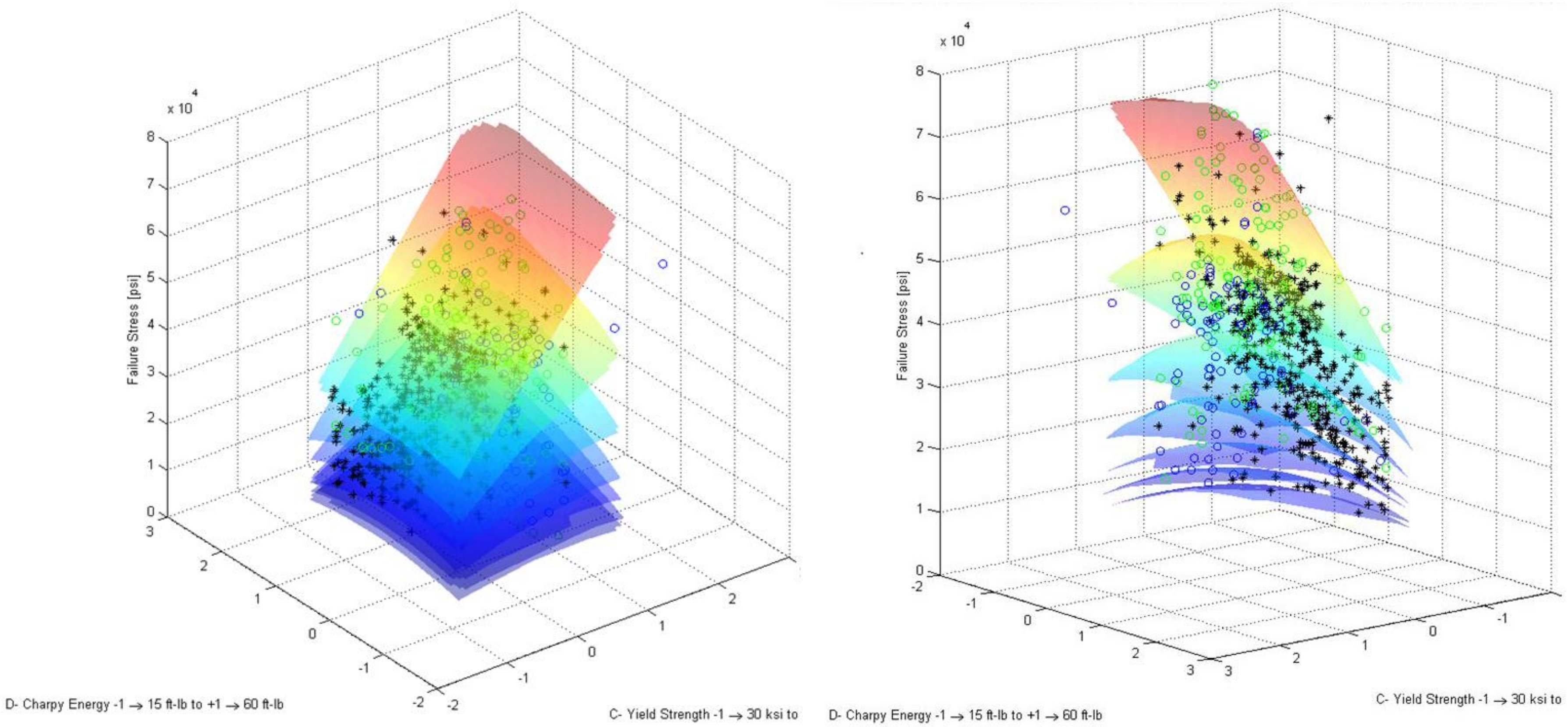
# Leak-rupture Boundary Determination Model

- Developed an engineering based leak rupture boundary with confidence limits
- Develop a software tool for the LRB model for operators to use for consequence analysis
- Finalized an easy to use software calculator for operators that predicts the boundary (as a %SMYS) between failure by leak and failure by rupture
- Being used for ECA and IVP prioritization (consequence of failure information)

# Successful Validation of the Model

## Leak-rupture Boundary Determination Model



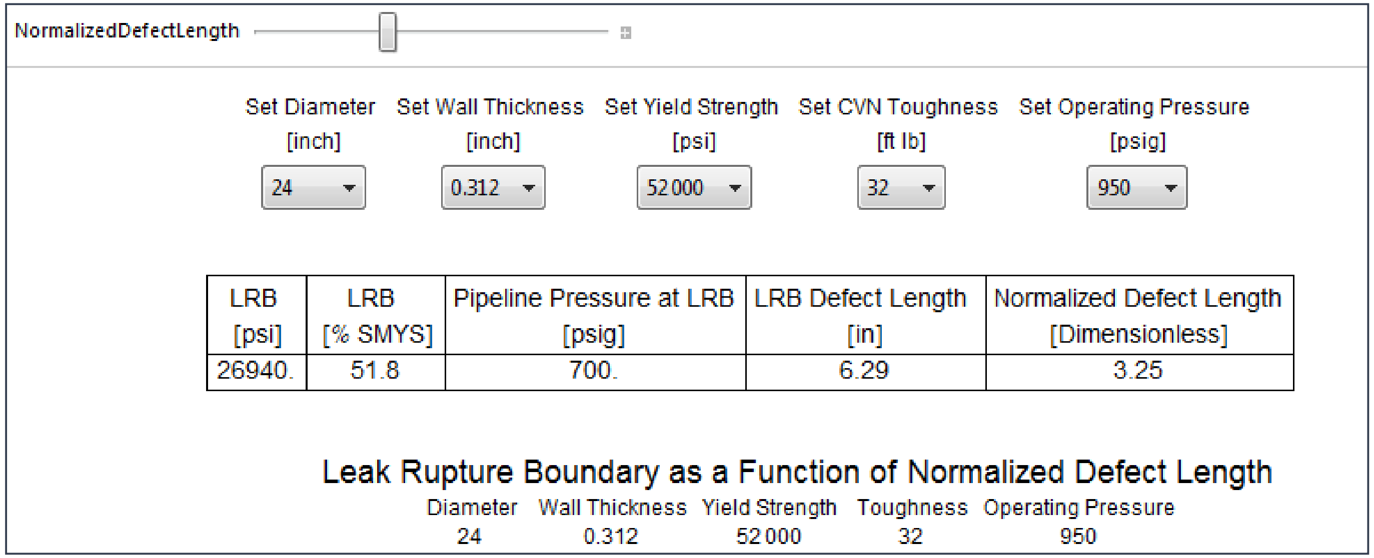




- 638 conclusive incident and full size test rupture points overlaid on
- 97.5% probability above LCL
- Rupture failure stress as a function of yield stress 30 to 80 ksi
- CVN 15 to 60 ft-lb
- C = 1 to 7 [top to bottom surfaces]

# LRB software tool / calculator

## Leak-rupture Boundary Determination Model

- Primary Five Data Inputs
  - Pipe diameter range: 6.625 to 48 inches
  - Pipe wall thickness range: 0.093 to 0.625 inches
  - Yield strength range: 24,000 to 88,000 psi
  - Toughness range: 1 to 160 ft lbs
  - Operating pressure range: 50 to 1,450 psig
- Final Input is Defect Length at Time of Failure

NormalizedDefectLength

| Set Diameter [inch] | Set Wall Thickness [inch] | Set Yield Strength [psi] | Set CVN Toughness [ft lb] | Set Operating Pressure [psig] |
|---|---|---|---|---|
| 24 | 0.312 | 52 000 | 32 | 950 |

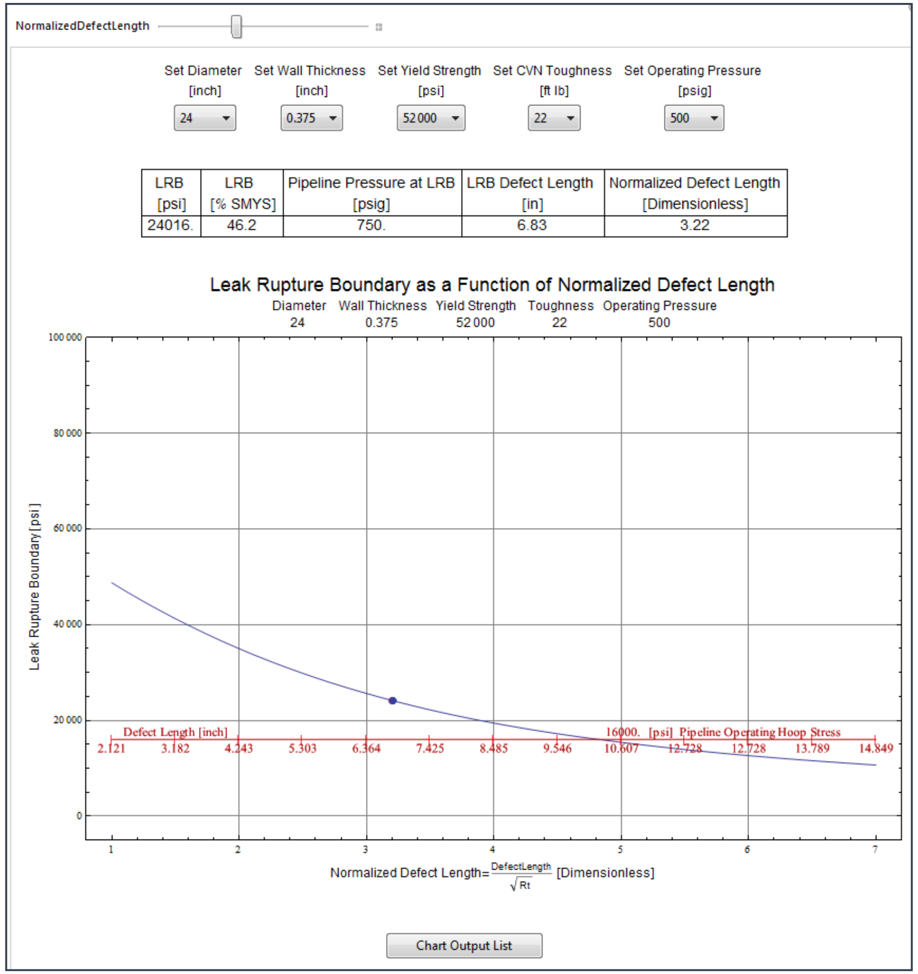
| LRB [psi] | LRB [% SMYS] | Pipeline Pressure at LRB [psig] | LRB Defect Length [in] | Normalized Defect Length [Dimensionless] |
|---|---|---|---|---|
| 26940. | 51.8 | 700. | 6.29 | 3.25 |

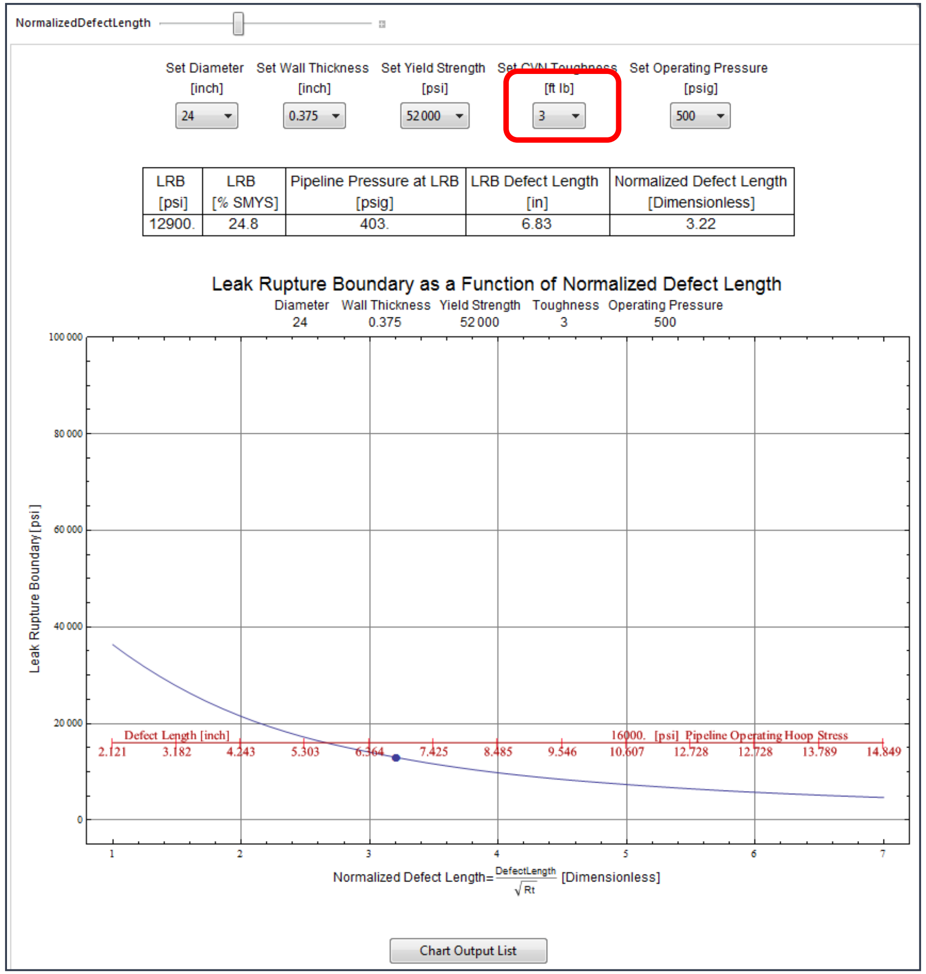
Leak Rupture Boundary as a Function of Normalized Defect Length

| Diameter | Wall Thickness | Yield Strength | Toughness | Operating Pressure |
|---|---|---|---|---|
| 24 | 0.312 | 52 000 | 32 | 950 |

# LRB Software Tool / Calculator – Plots

## Leak-rupture Boundary Determination Model



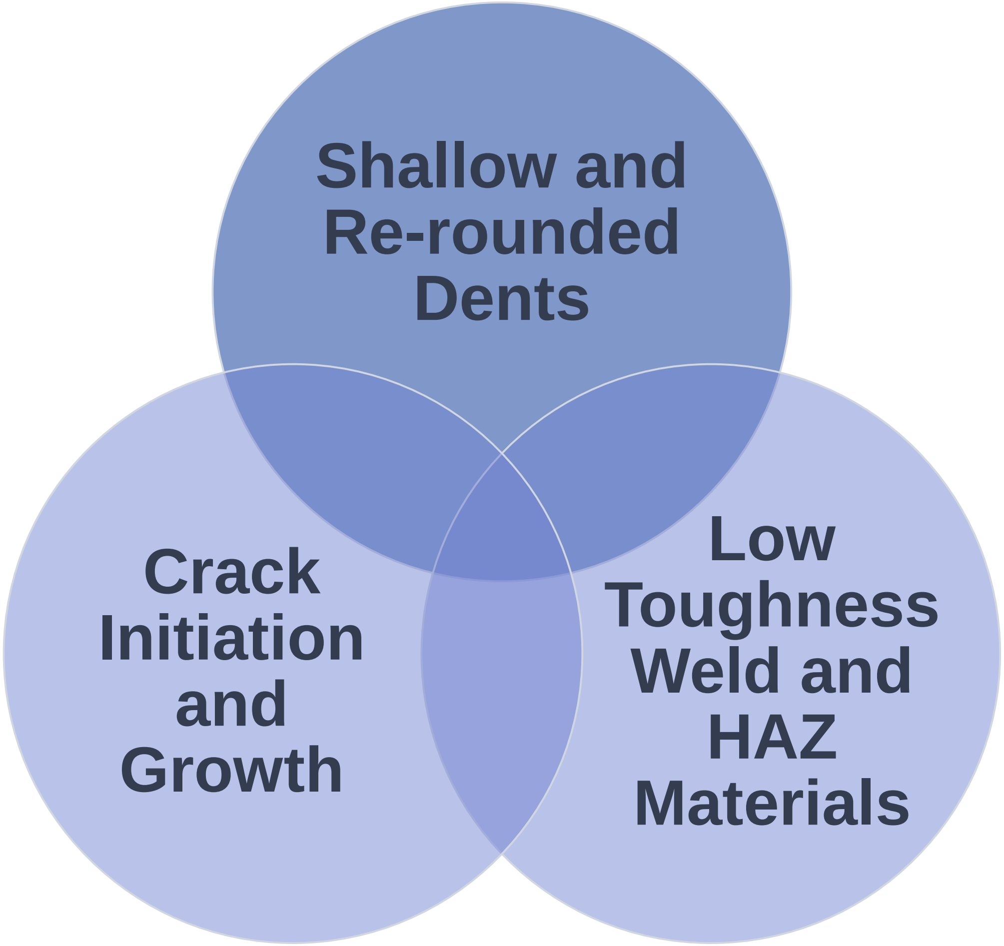
# Gaps in Understanding – Key Threat Interactions


> **Complex and Joint Threat**
  - Many pipeline incidents are the result of multiple, interacting causes, not a single threat.
  - Individual threats can each be at "acceptable" levels but when overlaid result in a significant threat to the pipeline or even a failure.

> **Benefits of Understanding**
  - Operators will be able to adequately identify combinations of threats and their associated risk.
  - Reduction of an operator's risk and enhancement of compliance with regulations.

# Shallow and Re-Rounded Dents + Cracking + Low Weld and HAZ Material Toughness

## Interacting/Overlapping Threat Gaps




- **Develop analysis methods that:**
  - Weight and properly synthesize all data sources
  - Recognize subject matter expertise
  - Understand physical and mechanical interactions of defects and material property gradients/zones.
  - Recommend multiple options for mitigation of problems to subject matter experts

# Summary - Past, Current and Future Work

- **There is a body of previous work on**
  - Critical crack determination and the relation to inspection detection limits
  - Crack initiation and growth as a function of pressure changes
  - Failure mode determination between stable leak and rupture
- **Future work should address dent, crack, and material threat interactions between**
  - Shallow and re-rounded dents (cold work, cracking, etc.)
  - Crack initiation and growth (within shallow/re-rounded dented and low toughness zones)
  - Crack/dent response to low toughness weld and heat affected zone material properties

# Questions